IMPROVED MODULE OF DYE SENSITIZED PHOTOVOLTAIC CELLS AND A METHOD FOR MAKING THE SAME

Field of the Invention

This invention relates to dye sensitized photovoltaic cells. More particularly, this invention relates to modules of multiple dye sensitized photovoltaic cells connected in parallel. Still more particularly, this invention relates to an improved module that increases the area of the cells in the module and improves the electrical connectivity between the cells in the module.

Prior Art

Photovoltaic cells, commonly referred to as solar cells, are a common clean energy-producing alternative. The most common type of photovoltaic cell is constructed from a semiconductor, such as silicon (Si). These cells are efficient energy sources. However, the fabrication and maintenance of such cells are cost prohibitive for many applications. Thus, those skilled in the art are constantly trying to provide low cost, alternative photovoltaic cells.

One type of photovoltaic cell that has been proposed as a less expensive alternative is a dye-sensitized photovoltaic cell. A dye-sensitized photovoltaic cell, which has a glass substrate with a thin film semiconductor layer with a nanostructure configuration, is layered on substrate to form a negative electrode. A counter electrode is then formed over the negative electrode. A dye is applied to the surface of the semiconductor material. The dye is a photovoltaic material that releases electrons to generate electricity when exposed to light. The dye-sensitized photovoltaic cell may also include electrolytes to replenish the electrons in the dye. Currently, the light to energy conversation in such cells is approximately 11%. Thus, there is great commercial interest in dye-sensitized photovoltaic cells.

However, it is a problem that the light to energy conversion efficiency decreases as the size of the cell increases. The lower conversion efficiency is the result of the slow movement of the electrons from the dye that is restricted by the nanoparticles of the semiconductor. Thus, as the size of the semiconductor layer increases, less of the electrons released by the dye migrate to a collection point.

To correct this problem, others have proposed connecting dye sensitized photovoltaic cells in parallel. Typically, the connection is made by placing electrodes between the cells. It is problem that any break in the electrodes may disrupt the parallel

connection between cells. Thus, those skilled in the art are constantly striving to design a module of dye sensitized photovoltaic cells that provides a higher light to energy conversion efficiency that is stable.

Summary of the Invention

The above and other problems are solved and an advance in the art is made by an improved module of a dye sensitized photovoltaic cell in accordance with this invention. A first advantage of a module in accordance with this invention is that the grid electrode surrounding the cells provides a stable connection of the cells connected in parallel. A second advantage of a module in accordance with this invention is that the area of the module for providing cells is maximized by allowing the substrates of the modules to be aligned. A third advantage of a module in accordance with this invention is that the insertion of the electrolytic material into the cell is improved by using through openings through the substrates into the cells.

In accordance with embodiments of this invention, a module of dye-sensitized photovoltaic cells is configured in the following manner. The module includes dye-sensitized photovoltaic cells. Each cell includes a dye-sensitized material that releases electrons in response to exposure to light. A grid collection electrode surrounds each of the dye-sensitized photovoltaic cells to collect the electrons released by the cells. The grid includes a first strip of conductive material along a first side of a first dye-sensitized photovoltaic cell on a first side of the module. A second strip of conductive material is along a second side of a last one of the dye-sensitized cells on a second side of the module. A third strip of conductive material is along a top side of each of the dye sensitized photovoltaic cells. A fourth strip of conductive material is along a bottom side of each of said plurality of dye-sensitized photovoltaic cells. Strips of conductive material are situated between adjacent sides of adjacent cells.

In accordance with some embodiments, the cells of the module are configured in the following manner. An upper substrate made of transparent material having an inner surface and an outer surface is on one side of the cells. A lower substrate made of transparent material having an inner surface and an outer surface is on a second side of the cells. The inner surface of the lower substrate faces the inner surface of said upper substrate. A first transparent electrode is formed on the inner surface of one of the upper and lower substrates. A second transparent electrode is formed on the inner surface of the other one of the substrates. Negative electrodes comprising nanoporous semiconductor material are formed on one of the first and second transparent electrodes. A photovoltaic dye is

absorbed into the surface of each of the nanoporous semiconductor negative electrodes. Positive electrodes are formed on a surface of a second one of the transparent electrodes. Each of the positive electrodes is a thin film of conductive material and is mated to one of the nanoporous semiconductor negative electrodes to form a dye-sensitized photovoltaic cell. The grid collection electrode is formed on one of said transparent electrodes surrounding each of the cells. In accordance with some of these embodiments, the grid collection electrode is also formed on a second one of the transparent electrodes.

In accordance with some embodiments of this invention, electrolytic material is inserted between each nanoporous semiconductor negative electrode and a mated positive electrode in each cell. The electrolytic material preferably includes a liquid solvent and a redox pair. In accordance with some of these embodiments, the liquid solvent is either an organic solvent or an ionic liquid. The organic solvents that may be used include, but are not limited to, acetonitrile, 3-methoxy propionitrile, diethyl carbonate, and propylene carbonate. The ionic liquids may be made of salt cations and/or anions. The redox pair may be iodine with iodide ions or bromine with bromide ions. In accordance with some of these embodiments, an additive may be added to the electrolytic material. The additive may be tert-butylpyridine and/or guanidinium thiocynate.

In accordance with some embodiments of this invention, first openings are defined through one of the upper and lower substrates. Each of these first openings is proximate one of the cells and is used to insert the electrolytic material into the cell. Sealants are then used to close these first openings. In some of these embodiments, second openings are also defined through one the substrates proximate each cell to facilitate the insertion of the electrolytic material into the cells. Second sealants are then used to close the second openings. In further ones of these embodiments, the first and second openings are distal from one another with respect to the cells. In still further ones of these embodiments, the first and second openings are proximate diagonally opposite ends of the cells. Preferably, the first and second openings are through the same substrate.

In accordance with some embodiments, the grid collection electrode is formed on one of the transparent electrodes. In accordance with other embodiments, a first portion of the grid electrode is formed on a first one of the transparent electrodes and a second portion is formed on the other transparent electrode. In accordance with some of these embodiments, an insulative material is formed between the first and second portions of the grid electrode to electrically insulate the portions that connect the cells in parallel.

In accordance with some embodiments of this invention, a first opening is defined through one of the upper and lower substrates. A second opening distal from the first opening is also defined through one of the substrates. A first connecting electrode is formed in the first opening connected to the grid electrode and a second connecting electrode is formed in the second opening connected to the grid electrode. The first and second connecting electrodes transfer electrons collected from the cells to an outside system. In accordance with some of these embodiments, the first and second openings are defined in diagonally opposite corners of the module. In accordance with further ones of these embodiments, the first opening and second openings are formed in different substrates. In accordance with still further ones of these embodiments, the upper and lower substrates are aligned.

In accordance with embodiments of this invention, the upper and lower substrates are glass. In accordance with various ones of these embodiments, the substrates may be borosilicate glass, quartz glass, or soda glass. In accordance with other embodiments, the upper and lower substrates are plastic. In accordance various ones of these embodiments, the substrates may be polyethylene terephthalate, polyethylene naphthalate, polybutylene terephthalate, polycarbonate, polystyrene, or polyimide.

In accordance with some embodiments, the first and second transparent electrodes are a conductive metal oxide. In some particular embodiments, the first and second transparent electrodes are indium doped tin oxide, zinc oxide, or fluorin doped tin oxide.

In accordance with some embodiments, the nanoporous semiconductor negative electrodes are made of TiO_2, ZnO, SnO_2, Nb_2O_5, WO_3, or Sb_2O_5.

In accordance with some embodiments of this invention, the dye is an iron complex, a ruthenium complex, a metal complex, or an organic dye. In some embodiments, the dye may be an iron complex and/or ruthenium complex having either terpyridine structures or bipyridine structures in a ligand. In embodiments where the dye is a metal complex, the dye may be phthalocyanine or porphin. In embodiments where the dye is an organic acid, the dye may be rhodamine, eosin, melocyanine, or courmarin.

In accordance with some embodiments of this invention, a module of dye-sensitized photovoltaic cells is assembled in the following manner. The process begins by forming a first transparent electrode on an inner surface of a first one of a first transparent substrate and a second transparent substrate. A second transparent electrode is formed on an inner

surface of a second one of said first transparent substrate and said second transparent substrate. Nanoporous semiconductor negative electrodes having a dye of photovoltaic material on a surface are formed on a first one of the first and second transparent electrodes. A layer of catalyst material is then deposited on a second one of said first and second transparent electrodes to act as positive electrodes in each of the photovoltaic cells formed with the nanoporous semiconductor negative electrodes. A first grid electrode surrounding the photovoltaic cells is formed on one of the first and second transparent electrodes and a second grid electrode is formed on the other transparent electrode. An insulation layer is then formed over one of the first and second grid electrodes. The first transparent substrate is then affixed to the second transparent substrate with inner surfaces of substrates affronting one another.

In accordance with some embodiments, a first opening is formed through one of the first and second transparent substrates for each of the cells. An electrolytic material is inserted into each of the cells through the first openings. The first openings are then sealed. In accordance with some of these embodiments, a second opening is also formed through one of the transparent substrates for each of the cells to facilitate the insertion of the electrolytic material into the cells. After the electrolytic material is inserted, the second opening is also sealed.

In accordance with some embodiments of this invention, a first connection opening is formed through a first one of the first and second substrates and a second connection opening is formed through a second one of the substrates. The first grid electrode is then connected to a first connecting electrode through the first connection opening and the second grid electrode is connected to a second connecting electrode through the second connection opening.

Brief Description of the Drawings

The above and other features and advantages of a module of dye-sensitized photovoltaic cells in accordance with this invention are described in the following detailed description and are shown in the following drawings:

Figure 1 illustrating a front view of a prior art module of a module of dye sensitized photovoltaic cells;

Figure 2 illustrating a front view of a prior art upper transparent substrate of a module of dye sensitized photovoltaic cells;

Figure 3 illustrating a front view of a prior art lower transparent substrate of a module of dye sensitized photovoltaic cells;

Figure 4 illustrating a front view of a module of dye sensitized photovoltaic cells in accordance with an embodiment of this invention;

Figure 5 illustrating a front view of an upper transparent substrate of a module of dye sensitized photovoltaic cells in accordance with an embodiment of this invention;

Figure 6 illustrating a front view of a lower transparent substrate of a module of dye of sensitized photovoltaic cells in accordance with an embodiment of this invention;

Figure 7 illustrating a cross sectional view along line Y of a module of dye sensitized photovoltaic cells in accordance with an embodiment of this invention;

Figure 8 illustrating a second cross sectional view along line X of a module of dye sensitized photovoltaic cells in accordance with an embodiment of this invention; and

Figure 9 illustrating a flow diagram for a process of producing of a module of dye sensitized photovoltaic cells in accordance with an embodiment of this invention.

Detailed Description

This invention relates to dye sensitized photovoltaic cells. More particularly, this invention relates to modules of multiple dye-sensitized photovoltaic cells connected in parallel. Still more particularly, this invention relates to an improved module that increases the area of the cells in the module and improves the electrical connectivity between the cells in the module. As dye-sensitized cells are well known in the art, a discussion of their operation is omitted from this discussion for brevity.

Figure 1 illustrates an embodiment of a prior art module of dye-sensitized cells. Module 100 includes dye-sensitized cells 105-112. Collection strip electrodes 115-123 are located along the sides of cells 105-112. Strips 116-122 are located between adjacent cells such that the adjacent sides of the adjacent cells abut one strip. Thus, cells 105-112 are connected in parallel. The ends of collection strip electrodes 115-123 connect to connection electrodes 125 and 130 which connection to external circuits (Not Shown) to provide a conduit for the electrons collected from cells 105-122 to the external circuit.

Figures 2 and 3 illustrate top portion 200 and bottom portion 300 of module 100. Top portion 200, shown in Figure 2, is a substrate of transparent material with nanoporous semiconductor negative electrodes 205-212 formed on a transparent electrode layered over the substrate. Nanoporous semiconductor negative electrodes 205-212 have a photovoltaic sensitive dye absorbed into the surface. First strip electrodes 215-223 are formed along the sides of nanoporous semiconductor negative electrodes 205-212. The first ends of first strip electrodes 215-223 are connected to connection electrode 125 formed along a first end of the transparent substrate.

Bottom portion 300, shown in Figure 3, is a substrate of transparent material with positive electrodes 305-312 formed on a transparent electrode layered over the substrate. Each of positive electrodes 305-312 is mated with a corresponding nanoporous semiconductor negative electrode 205-212 to form a dye-sensitized cell. Second strip electrodes 315-323 are formed along the sides of positive electrodes 305-312. The second ends of second strip electrodes 315-323 are connected to connection electrode 130 formed along a second end of the transparent substrate that is opposite to the first end on which connection electrode 125 is connected to first strip electrodes 215-223.

As can be seen from Figures 1-3, the two ends of first and second portions cannot be aligned in order to allow the first end of first portion 200 and the second end of second portion 300 to extend out of module 200 to expose connection electrodes 125 and 130 for connection to external circuitry. Thus, the size of the cells cannot be maximized. Furthermore, strip electrodes 115-123 connect cells 105-112 in parallel and any defect or break in strip electrodes breaks the parallel connection of cells 105-112. Thus, the system is susceptible to breakage that increases the handling and maintenance costs of module 100.

Figure 4 illustrates module 400 that is a module of dye-sensitized cells in accordance with an embodiment of this invention. Module 400 includes dye-sensitized cells 405-412. Grid collection electrodes 415-423, 440 and 450 surround the cells to collect released electrons and to connect the cells in parallel. Strips of conductive material 415 and 423 are located along the outer sides of cells 405 and 412 at opposing ends of module 400. Strip electrodes 416-422 are between adjacent cells 405-412 such that the adjacent sides of cell 405-412 abut one strip. First end strip electrode 440 is a strip of conductive material along a first end of cells 405-412 and second end strip electrode 450 is a strip of conductive material along a second end of cells 405-412. The use of grid electrodes surrounding the cells assure that the parallel connection between electrodes is maintained even if there is a defect in one of the strips as the connection of the cells remains intact through the connections to other portions of the cells. Connection electrodes 425 and 430 are connected to grid electrodes on opposing ends of module 400 through openings through transparent substrates on each of the first and second ends of module 400.

In the shown embodiment, first connection electrode 425 is connected through an opening in a first transparent substrate on a corner on a first side of a first end of module 400 and second connection electrode 430 is connected through an opening in a second transparent on a corner on a second side of a second end of module 400 that is diagonally

opposite the first opening. However, one skilled in the art will recognize that that the openings may be in other positions along the first and second ends of module 400 without departing from this invention. Preferably, the openings are diagonal from one another to maximize the distance between electrodes to maximize the electrons collected from the cells.

Figures 5 and 6 illustrate top portion 500 and bottom portion 600 of module 400. Upper portion 500 is formed on upper transparent substrate 555. Upper transparent substrate 555 is made of transparent material. Nanoporous semiconductor negative electrodes 505-512 are formed on a transparent electrode layered over substrate 555. Nanoporous semiconductor negative electrodes 505-512 have a photovoltaic sensitive dye absorbed into the surface.

A first portion of the grid collection electrodes surround nanoporous semiconductor negative electrodes 505-512. Strips of conductive material 515 and 523 of a first portion of the grid collection electrodes are along the outer sides of negative electrodes 505 and 512 at opposing ends of module 500. Strip electrodes 516-522 are between adjacent electrodes 505-512 such that the adjacent sides of electrodes 505-512 abut a common strip. First end strip electrode 540 is a strip of conductive material along a first end of electrodes 505-512 and second end strip electrode 550 is a strip of conductive material along a second of electrodes 505-512.

Second connection electrode 430 connects to the first portion of the grid electrode via an opening through lower portion 600 of module 500 (Shown in Figure 6). Top portion 500 includes first connection opening 525 through substrate 555. First connection electrode 425 is connected to a second portion of the grid collection electrode (Shown in Figure 6) through first connection opening 525. In the shown embodiment, first connection opening 525 is in a corner on a first end of a first side of substrate 555. First connection opening 525 and second connection opening 630 are preferably diagonally arranged with respect to one another to maximize the distance between connection electrodes which in turn maximizes the electrons collected.

Bottom portion 600 is formed on lower substrate 655. Lower substrate 655 is made of transparent material. Positive electrodes 605-612 are formed on a transparent electrode layered over lower transparent substrate 655. Each of positive electrodes 605-612 is mated with a corresponding nanoporous semiconductor negative electrode 505-512 to form one of dye-sensitized cells 405-412. One skilled in the art will recognize that positive electrodes

605-612 are mated with corresponding nanoporous semiconductor negative electrode 505-512.

A second portion of the grid collection electrodes are formed on the transparent electrode over substrate 655 and surround positive electrodes 605-612. Strips of conductive material 615 and 623 of the second portion of the grid collection electrodes are along the outer sides of electrodes 605 and 612, at opposing ends of module 400. Strips 616-622 are between adjacent electrodes 605-612 such that the adjacent sides of electrodes 605-612 abut a common strip. First end strip 640 is a strip of conductive material along a first end of electrodes 605-612 and second end strip 650 is a strip of conductive material along a second of electrodes 605-612.

First connection electrode 425 connects to the second portion of the grid collection electrodes via an opening through upper portion 500 of module 400 (Shown in Figure 5). Lower portion 600 includes second connection opening 630 through substrate 655. Second connection electrode 430 is connected to a first portion of the grid collection electrodes (Shown in Figure 5) through second connection opening 630. In the shown embodiment, second connection opening 620 is in a corner on a second end of a second side of substrate 655. First connection opening 525 and second connection opening 630 are preferably diagonally arranged with respect to one another to maximize the distance between connection electrodes to in turn maximize the electrons collected. However, one skilled in the art will recognize that other arrangements of the connection openings are possible without departing from this invention. In accordance with this invention, the connection openings need only be through the opposite substrate to allow connection of the connection electrodes to grid electrodes. The connection openings allow all of the edges of upper portion 500 and lower portion 600 to be aligned. Thus, the size of the cells in the module may be increased.

Lower portion 600 also includes first openings 660-667 through substrate 655 into each of cells 405-412. First openings 660-667 are used to insert electrolytic material into each of cells 405-412. First openings 660-667 are sealed after the electrolytic material is inserted into cells 405-412. To prevent bubbles or vacuums from forming in the electrolytic material inserted into the cells and to assist in the flow of the electrolytic material into cells 405-412, second openings 670-677 may also be formed through substrate 655. Second openings 670-677 are then sealed after the electrolytic material is inserted. Those skilled in the art will recognize that the seals of the first and second openings may be removable to periodically replenish the electrolytic material without departing from this invention. To best

facilitate the insertion of the catalytic material, first openings 660-667 are diagonally opposite second openings 670-677 in each cell 405-412. Preferably, the openings are in diagonally opposite corners to maximize the distance. However, one skilled in the art will recognize that other configurations of the first and second openings may be used without departing from this invention.

Figures 7 and 8 are cross sectional views along lines X and Y shown in Figure 4 to describe the components of module 400. Figure 7 illustrates a cross sectional view of module 400 along line Y. As shown in Figure 7, module 400 is made of upper transparent substrate 555 and lower transparent substrate 655. Upper transparent substrate 555 and lower transparent substrate 655 may be made of any transparent material. Preferably, transparent substrate 555 and lower transparent substrate 655 are made of either glass or plastic. Examples of types of glass that may be used to form upper transparent substrate 555 and lower transparent substrate 655 include, but are not limited to, borosilicate glass, quartz glass, and soda glass. Examples of types of plastics that may be used to form upper transparent substrate 555 and lower transparent substrate 655 include, but are not limited to, polyethylene terephthalate, polyethylene naphthalate, polybutylene terephthalate, polycarbonate, polystyrene, and polyimide. One skilled in the art will recognize that different types of materials may be used to form the two substrates without departing from this invention.

First transparent electrode 712 is formed on an inner surface of upper transparent substrate 555 and second transparent electrode 711 is formed on an inner surface of lower transparent substrate 655. First transparent electrode 712 and second transparent electrode 711 may be a conductive metal oxide. Examples of conductive metal oxides that may be used to form first transparent electrode 712 and second transparent electrode 711 include, but are not limited to, indium doped tin oxide, zinc oxide, or fluorin doped tin oxide. Preferably, first transparent electrode 712 and second transparent electrode 711 are transparent or substantially transparent. However, other types of materials may be used without departing from this invention. Furthermore, the type of conductive metal oxide used to form the transparent electrodes will depend upon the type of material used to form upper substrate 555 and lower substrate 655. One skilled in the art will further recognize that first transparent electrode 712 and second transparent electrode 711 may be formed of different materials without departing from this invention.

A nanoporous semiconductor negative electrode is formed for each cell over first transparent electrode 712 as shown by nanoporous semiconductor negative electrode 605 in

Figure 6. Nanoporous semiconductor negative electrodes 605-612 are formed of titanium dioxide (TiO_2). However, other nanoporous semiconductors may be used included, but not limited to, ZnO, SnO_2, Nb_2O_5, WO_3, and Sb_2O_5. A photovoltaic sensitized dye is then absorbed into the surface of nanoporous semiconductor negative electrodes. The dye may be, but is not limited to, an iron complex, a ruthenium complex, a metal complex, and an organic dye. An iron or ruthenium complex may contain terpyridine structures or bipyridine structures in a ligand. Metal complexes that may be used include, but are not limited to, phthalocyanine and porphin. Organic dyes that may be used include, but are not limited to, rhodamine, eosin, melocyanine, and courmarin. One skilled in the art will recognize that derivatives of any of the above listed dyes may also be used without departing from the invention. Furthermore, one skilled in the art will recognize that the type of dyes that may be used will depend upon the material used to form the nanoporous semiconductor negative electrodes.

A counter positive electrode is formed on lower substrate 655 to form a dye-sensitized cell with nanoporous semiconductor negative electrode as is shown by positive electrode 505 in Figure 5. Preferably, the counter positive electrode is made of a material that acts as a catalyst for regeneration of a redox pair in the dye-sensitized cell. The positive electrode may be formed of the catalyst material coated on an insulation support. The catalyst material may be, but is not limited to platinum and carbon.

Electrolytic material 715 is inserted into each cell between the positive electrode and the nanoporous semiconductor negative electrode. Electrolytic material 715 may be an organic solvent electrolyte or an ionic liquid based electrolyte that in each case is contained in a redox pair. For purposes of this description, an ionic liquid is a room temperature, molten salt which is an electrochemically active salt that has a melting point lower than ambient temperature. Electrolytic material 715 is composed of a redox pair contained in a liquid solvent. The liquid solvent may be a pure organic solvent or an ionic liquid, or a combination of these solvents. Examples of organic solvents that may be used include, but are not limited to, acetonitrile, 3-methoxy propionitrile, diethyl carbonate, and propylene carbonate. Examples of the ionic liquid that may be used include, but are not limited to salts made of cations, such as quaternary imidazolium based cations and anions; iodide ions or dicyanoamide anions; and bistrifluoromethyl sulfonylimido anions. The redox pair that may be used include is not particularly limited. Examples of redox pairs that may be used include, but are not limited to, iodine with iodide ions and bromine with bromide ions. Preferably, the redox pair is iodine with iodide ions. Additives including, but not limited to,

tert-butylpyridine, and guanidinium thiocyanate may also be added to the electrolyte without departing from this invention.

Figure 8 illustrates a cross sectional view of module 400 along line X in Figure 4. A discussion of the components shown in Figure 7 is not repeated for brevity. In Figure 8, the first and second portions of grid electrodes are formed on first transparent electrode 712 and second transparent electrode 711 around the positive and negative electrodes as shown by strips 515-523 and 615-623. Preferably, the portions of the grid electrodes are formed to a depth that prevents contact between the portions. More preferably, the portions of the grid electrodes are deposited as a thin film of conductive material. The grid electrodes may be formed of a conductive material such as silver paste, copper paste, carbon paste, and the like. However, any conductive material may be used without departing from this invention.

Furthermore, insulating film 805 may be between the portions of the grid electrodes. Insulating film 805 may be thermoplastic film; thermo-setting or UV-curable adhesive; glass frit or ceramic insulation. Insulating film 805 may be used to bond the portions of the module together. Insulating film 805 may provide insulation to prevent direct electrical contact between the electrodes on the separate portions of module 400.

Figure 9 illustrates an embodiment of a process for assembling a module of dye-sensitized photovoltaic cells in accordance with the invention. Process 900 begins in step 905 by forming first connection opening 525 and second connection opening 630 in opposing ends of an upper and a lower transparent substrate. In the embodiment shown in Figures 4-8, the openings may be formed by removing diagonally opposite corners from each of upper substrate 555 and lower substrate 655. First openings 660-667 and second openings 670-677 are formed through one of upper substrate 555 and lower substrate 655 in step 907. As shown in Figure 6, first and second openings are preferably, diagonally opposite one another in each cell. In step 910, a first transparent electrode 712 is formed on upper transparent substrate 555 and second transparent electrode 711 is formed on lower transparent substrate 655. The formation of the transparent electrodes is not limited to a particular process. Examples of processes that be used include, but are not limited to chemical vapor deposition (CVD), spray decomposition, and sputtering. One skilled in the art will recognize that steps 905 and 910 are interchangeable. One skilled in the art will also recognize that the step of forming first and second openings (as described in step 907) may be carried out instead after the first and second transparent electrodes have been formed on the respective transparent substrates as set out in step 910.

In step 915, the nanoporous semiconductor negative electrodes 505-512 are formed on a first one of first transparent electrode 712 and second transparent electrode 711. The method of forming nanoporous semiconductor negative electrodes 505-512 is not limited to a particular process. Examples of processes that may be used include, but are not limited to, methods in which a dispersion solution that is obtained by dispersing commercially available semiconductor nanoparticles in a suitable dispersion medium; a colloid solution that can be prepared using a sol-gel method after desired additives are added (if required), using a known coating method such as a screen printing method, a spin coating method, a doctor blade method, an ink-jet method, a roll coating method, a spray coating method, or the like. Sintering of the nanoporous semiconductor can be achieved via heat or pressure depending on the material of upper substrate 555.

In step 920, the positive electrodes of the cells are formed on a second one of first transparent electrode 712 and second transparent electrode 711. The positive electrodes may be formed by screen printing a catalyst material onto the transparent electrode. One skilled in the art will recognize that other methods may be used without departing from this invention.

In step 925, the portions of the grid collection electrodes are formed around the cell electrodes. The grid collection electrodes may be formed by screen printing. However, those skilled in the art will recognize that other processes for forming the portions of the grid collection electrodes may be used without departing from this invention.

In step 930, an insulation layer that may include an adhesive is applied over both portions of module 400 formed on substrates 555 and 655.

In step 940, the edges of upper portion 500 and lower portion 600 are aligned. The portions are then affixed to one another in step 945. In step 950, the connection electrodes for connecting the portions of the grid electrodes to outside circuitry are connected to the portions of the grid collections electrodes through the connection openings formed in step 905. Furthermore, one skilled in the art will recognize that the process described in step 950 may be combined with the process described in step 925 using a screen printing technique. Those skilled in the art will recognize that the combination of the processes described in step 925 and step 950 are not limited to just screen printing techniques.

In step 955, the electrolytic material is inserted into each cell. Process 900 then ends at step 960 by sealing first openings 660-667 and second openings 670-677 in each of the cells.

The following is an example of a process for making a module of dye sensitized cells in accordance with an embodiment of this invention. Titanium oxide (TiO_2) films for nanoporous semiconductor negative electrodes; platinum (Pt) films for counter electrodes; and silver (Ag) films for both the grid electrodes and connection electrodes were prepared using a screen printing method. The screen mask for TiO_2, Pt, and Ag films were all of 230 mesh. Two 100 mm × 100 mm size fluorine doped tin oxide (FTO) conductive transparent glass (TEC 15, LOF Industries) with one corner removed in advance were used as the substrates of dye-sensitized solar cell module.

Ag film with a network pattern was screen printed on the FTO glass for both negative electrodes and counter electrodes using a kind of low-temperature Ag paste (BYD 550, Shanghai Baoyin Electronic Materials Ltd.). The Ag lines were dried at 150°C for 10 min. The Ag-coated FTO glass for counter electrode was then sintered at 500°C for 5 min.

A 10 μm thick TiO_2 film that was 20 nm in size and a 4 μm thick TiO_2 film that was 300 nm in size were coated by screen printing using a first TiO_2 paste (20wt% TiO_2 with 20 nm size, 10wt% ethyl cellulose and 70wt% terpineol) and a second TiO_2 paste (20wt% TiO_2 with 300 nm size, 10wt% ethyl cellulose and 70wt% terpineol) on FTO glass with Ag lines. The printed TiO_2 films were then sintered at 500°C for 15 min.

The sintered TiO_2 was soaked in 0.5 mm cis-diisothiocyanato-bis(2,2'-bipyridyl-4,4'-dicarboxylato) ruthenium(II) bis(tetrabutylammonium) acetonitrile/tert-butanol (1:1) dye solution for 20 hours. After the soaking, the TiO_2 was washed with acetonitrile. The negative electrode was then dried and completed.

Pt films were then prepared by screen printing using Pt pastes (1wt% $H_2PtCl_6 \cdot 6H_2O$, 5wt% ethyl cellulose and 94wt% terpineol) on FTO glass with sintered Ag lines. The printed Pt films were then sintered at 400°C for 10 min. to complete the counter electrode.

Thermoplastic film (Surlyn 1702, Dopond) was then used for sealing and insulation. The thermoplastic film was placed between negative electrodes and counter electrodes. The dye-sensitized solar cell module was then assembled by completely overlapping the two substrates. Hot-press equipment was used to melt the thermoplastic film and form the

complete structure. An electrolyte (1.0M 1-propyl-3-methylimidazolium iodide, 0.03M iodine, 0.1M guanidinium thiocyanate and 0.5M 4-tert-butylpyridine in acetonitrile) was then inserted into the cell through the pre-drilled holes in the counter electrode. Thermoplastic film was also used to the seal the pre-drilled holes.

Thus, the large-size dye-sensitized solar cell module was completed. A high light-to-energy conversion efficiency of 5.1% was achieved under solar simulator test (AM-1.5, 1 Sun condition).

The above is a description of embodiments of an improved module of dye sensitized photovoltaic cells in accordance with this invention. It is envisioned that other can and will design alternative embodiments of this invention from the above description that infringe on this invention as set forth in the following claims.

What is claimed is:

1. A module of a plurality of dye sensitized photovoltaic cell comprising:

a plurality of dye sensitized photovoltaic cells wherein each of said plurality of dye sensitized photovoltaic cells include a dye sensitized material that releases electrons in response to exposure to light; and

a grid collection electrode surrounding each of said plurality of dye sensitized photovoltaic cells for collecting said electrons released by said plurality of dye sensitized photovoltaic cells comprising:

a first strip of conductive material along a first side of a first one of said plurality of photovoltaic cells on a first side of said module,

a second strip of conductive material along a second side of a last one of said plurality of dye sensitized photovoltaic cells,

a third strip of conductive material along a top side of each of said plurality of dye sensitized photovoltaic cells,

a fourth strip of conductive material along a bottom side of each of said plurality of dye sensitized photovoltaic cells, and

a plurality of strips of conductive material wherein each of said plurality of strips in adjacent sides of adjacent ones of said plurality of dye sensitized photovoltaic cells.

2. The module of claim 1 wherein said plurality of dye-sensitized photovoltaic cells comprise:

a upper substrate made of transparent material having an inner surface and an outer surface;

a lower substrate made of transparent material having an inner surface and an outer surface wherein said inner surface of said lower substrate faces said inner surface of said upper substrate;

a first transparent electrode formed on said inner surface of a first one of said upper substrate and said lower substrate;

a second transparent electrode form on said inner surface of a second one of said upper substrate and said lower substrate;

a plurality of nanoporous semiconductor negative electrodes having formed on a surface of one of said first transparent electrode and said second transparent electrode;

a photovoltaic dye absorbed into a surface of each of said plurality of nanoporous semiconductor negative electrodes;

a plurality of positive electrodes formed on a surface of a second one of said first transparent electrode and second transparent electrode wherein each one of said plurality of positive electrodes is a thin film of conductive material and is mated to one of said plurality of nanoporous semiconductor negative electrodes to form one of said plurality of dye sensitized photovoltaic cells; and

wherein said grid collection electrode is formed on a first one of said first and second transparent electrodes surrounding each of said plurality of cells.

3. The module of claim 2 wherein said grid collection electrode is also formed on a second one of said first and second transparent electrodes surrounding each of said plurality of cells.

4. The module of claim 2 further comprising:

electrolytic material inserted between each said a plurality of nanoporous semiconductor negative electrodes and a mated one of said plurality of positive electrodes in each of said plurality of cells.

5. The module of claim 4 wherein a plurality of first openings are defined through one of said upper and lower substrates further wherein each of said plurality of first openings is proximate one of said plurality of cells to insert said electrolytic material into said one of said plurality of cells, said module further comprising:

a plurality of first sealants wherein each of said plurality of first sealants closes one of said plurality of first openings through said one of said upper and lower substrates.

6. The module of claim 5 wherein a plurality of second openings are defined through one of said lower and upper substrates further wherein each of said plurality of second openings is proximate one of said plurality of cells to insert said electrolytic material into said one of said plurality of cells, said module further comprising:

a plurality of second sealants wherein each of said plurality of second sealants closes one of said plurality of second openings through said one of said upper and lower substrates.

7. The module of claim 6 wherein one of said plurality of first openings in one of said plurality of cells is distal from one of said plurality of second openings in said one of said plurality of dye sensitized cells.

8. The module of claim 7 wherein said one of plurality of first openings in one of said plurality of cells diagonally opposed to said one of said plurality of second openings in said one of said plurality of dye sensitized cells.

9. The module of claim 5 wherein said plurality of first openings and said plurality of second openings are on a same one of said upper and lower substrates.

10. The module of claim 2 wherein said grid electrode is formed on one of said first and second transparent electrodes.

11. The module of claim 2 wherein said grid electrode comprises:

a first portion that is formed on said first transparent electrode surrounding said plurality of cells; and

a second portion that is formed on said second transparent electrode surrounding said plurality of cells.

12. The module of claim 11 further comprising:

insulative material between said first and second portions of said grid electrode to electrically insulate said first portion from said second portions of said grid electrode to connect said plurality of cells in parallel.

13. The module of claim 2 wherein a first opening is defined through one of said upper and lower substrates and a second opening distal from said first opening defined through one of said upper and lower substrates, said module further comprising:

a first connecting electrode formed in said first opening connected to said grid electrode; and

a second connecting electrode formed in said second opening connected to said grid electrode wherein said first and second connecting electrodes transfer electrons to an outside system.

14. The module of claim 13 wherein said first and second openings are defined in diagonally opposite corners of said module.

15. The module of claim 13 wherein said first opening is formed through a first one of said upper and lower substrates and said second opening is formed through a second one of said upper and lower substrates.

16. The module of claim 13 wherein said first and second openings are formed in a same one of said upper and lower substrates.

17. The module of claim 13 wherein edges of said upper and lower substrates are aligned.

18. The module of claim 2 wherein said first and second transparent electrodes are a conductive metal oxide.

19. A method for producing a module including a plurality of dye sensitized photovoltaic cells comprising:

forming a first transparent electrode on an inner surface of a first one of a first transparent substrate and a second transparent substrate;

forming a second transparent electrode on an inner surface of a second one of said first transparent substrate and said second transparent substrate;

forming a plurality of nanoporous semiconductor negative electrodes having a dye of photovoltaic material on a surface of each of said plurality of nanoporous semiconductor negative electrodes on a first one of said first and second transparent electrodes;

depositing a layer of catalyst material on a second one of said first and second transparent electrodes wherein said layer of catalyst matetrial acts as positive electrodes in each of a plurality of photovoltaic cells formed with said plurality of nanoporous semiconductor negative electrodes;

forming a first grid electrode surrounding said plurality of photovoltaic on said first one of said first and second transparent electrodes;

forming a second grid electrode on said second one of said first and second transparent electrodes;

forming an insulation layer over one of said first and second grid electrodes; and

affixing said first transparent substrate to said second transparent substrate with said inner surface of said first transparent substrate affronting said inner surface of said second transparent substrate.

20. The method of claim 19 further comprising:

forming a first opening through one of said first and second transparent substrates for each of said plurality of cells;

inserting electrolytic material into each of said plurality of cells through said first opening of each of said plurality of cells; and

sealing said first opening of each of said plurality of cells responsive inserting said electrolytic material into each of said plurality of cells.

21. The method of claim 20 further comprising:

forming a second opening through one of said first and second transparent substrates for each of said plurality of cells to facilitate said insertion of said electrolytic material; and

sealing said second opening of each of said plurality of cells responsive inserting said electrolytic material into each of said plurality of cells.

22. The method of claim 21 wherein said first and second opening are in a same one of said first and second substrate.

23. The method of claim 21 wherein said first and second openings are diagonally opposite in each of said plurality of cells.

24. The method of claim 19 further comprising:

forming a first connection opening through a first one of said first and second substrates;

forming a second connection opening through a second of said first and second substrates;

connecting said grid electrode formed on said first one of said first and second substrates to a first connecting electrode through said first connection opening; and

connecting said grid electrode on said second one of said first and second substrates to a second connection electrode through said second connection opening.

25. The method of claim 24 wherein said first and second connection openings are on opposing corners of said module.

26. The method of claim 25 wherein said first and second openings are triangular and said first and second connection electrodes are triangular.

27. The method of claim 24 wherein said step of affixing said first and second substrates comprises:

aligning all common edges of said first and second substrates with one another.

28. The method of claim 19 wherein said first and second transparent electrodes are a conductive metal oxide.